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# Climate change - a storm brewing for hydro?

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**ABSTRACT:** The increased use of renewable energy is critical to reducing emissions of greenhouse gases in order to limit climatic change. Hydropower is currently the major renewable source contributing to electricity supply, and its future contribution is anticipated to increase significantly. However, the successful expansion of hydropower is dependent on the availability of the resource and the perceptions of those financing it. Global warming and changes in precipitation patterns will alter the timing and magnitude of river flows. This will affect the ability of hydropower stations to harness the resource, and may reduce production, implying lower revenues and poorer returns. Electricity industry liberalisation implies that, increasingly, commercial considerations will drive investment decision-making. As such, investors will be concerned with processes, such as climatic change, that have the potential to alter investment performance. This paper examines the potential impact of climatic change on hydropower investment. It introduces a methodology for quantifying changes in investment performance, and presents preliminary results from a case study. These inform discussion of the implications for future hydropower provision and our ability to limit the extent of climatic change.

## 1 INTRODUCTION

Climatic change is expected to be the outcome of increases in atmospheric concentrations of “greenhouse” gases resulting from human activities (Houghton et al., 1990). The emissions are caused, in part, by fossil-fuelled electricity generation, and as world energy demand is expected to at least triple by the end of the twenty-first century (Nakicenovic et al., 1998), emissions and hence concentrations are expected to rise considerably. The impact of climatic change could be significant especially if less developed countries expand their electricity supply systems using fossil fuels.

In an attempt to control greenhouse gas concentrations and slow down the greenhouse process, governments are aiming to cut or stabilise emissions relative to 1990 levels. To achieve this target, the energy sector will have to change the way it operates: it could reduce its reliance on fossil fuels, use more renewable energy, and practice greater energy efficiency. Together with other means, such measures should allow the climate to reach and stabilise at a new equilibrium level.

Over the next century or so, during which this new set of equilibrium conditions will be reached, generating plant could be expected to be replaced twice (the design life of the electromechanical equipment in a power station is rarely greater than

50 years). Increasing demand and the move to deregulated electricity systems means that private investment is likely to be used to fund new and replacement capacity. This, in turn, means that the perceptions of current and future investors will play a major role in whether emission cuts are achieved.

## 2 CLIMATE CHANGE

Many greenhouse gases, including carbon dioxide ( $\text{CO}_2$ ), occur naturally and keep the earth warm by trapping heat in the atmosphere. However, since the Industrial Revolution, man-made sources of  $\text{CO}_2$  have added greatly to atmospheric concentrations. In particular, transportation and the burning of fossil fuels for electricity generation are frequently cited as major sources.

Enhanced levels of greenhouse gas concentrations are predicted to cause a significant rise in temperature over the next century, with rates of increase anticipated to be greater than at any time in the recent past. The current consensus is that under present rates of economic and population growth, global mean temperatures will rise by around  $3^\circ\text{C}$  by the end of the century. However, there are indications are that the increase may be as much as  $5.8^\circ\text{C}$  (IPCC, 2001). Figure 1 shows that throughout the twentieth century, temperatures have risen as has the

rate of increase. Shown also is the expected rise with current emissions trends (IS92a) and the range of rises under alternative scenarios. The rise in temperature is expected to be accompanied by increases in global mean precipitation levels of up to 15% (Houghton et al., 1990).

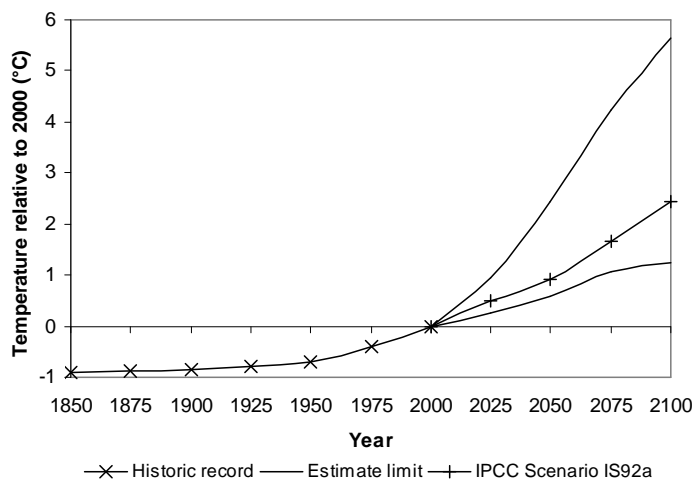


Figure 1. Historic and future temperature rise (adapted from Houghton et al., 1990 and IPCC, 2001)

Many predictions of future climate are based on the output of complex numerical General Circulation Models (GCMs) which simulate physical processes in the atmosphere and oceans. Although GCMs differ in the detail of their methodologies, most agree on the general temperature trend (Gates et al. 1990, Wood et al. 1997).

There are many potential impacts of climatic change including: loss of land due to sea level rise, damage from increased levels of storm activity, and threats to bio-diversity (Houghton et al., 1990).

Under the Kyoto Protocol (UNFCCC, 1998) most countries agreed that they would limit greenhouse gas emissions. As electricity production accounts for a significant portion of the emissions, much of the burden will fall on this sector. Increased use of renewable energy sources, including hydropower, is one suggested way in which the emissions targets can be met.

Unfortunately, the very fact that renewable energy resources harness the natural climate means that they are at risk from changes in climatic patterns. As such, changes in climate due to higher greenhouse concentrations may frustrate efforts to limit the extent of future climatic changes.

### 3 CLIMATE IMPACTS

Hydropower is currently the only major renewable energy source contributing to global electricity supply. Given the expectation of a threefold increase in hydropower production over the next century, the

continuing significant contribution from hydropower warrants a closer investigation of the potential impacts of changing climate on hydro.

#### 3.1 River Flows

At first glance, rising global precipitation would seem to provide opportunities for increased use of hydroelectricity. Unfortunately, such increases will not occur uniformly over time or space, and many regions are projected to experience significant reductions in precipitation. In addition, the temperature rise will lead to increased evaporation. The combination of changes in precipitation and evaporation will have profound effects on catchment soil moisture levels. The soil provides storage and regulates runoff regimes. Drier soil absorbs more rainfall, tending to reduce the quantity of water available for runoff, while more saturated soils absorb less rainfall increasing the likelihood of flooding.

In river basins that experience significant snow-fall, higher temperatures will tend to increase the proportion of wet precipitation. This may increase winter river flows, lead to an earlier spring thaw and reduce summer low flows (Gleick, 1986). Figure 2 shows a hypothetical example of this.

Climate change impacts studies have, in general, relied on rainfall-runoff models to translate changes in precipitation and temperature into altered river flows. GCMs provide information on how climatic variables may change in the future. Unfortunately, each GCM tends to predict a different change in temperature and precipitation, which results in significant and often contradictory differences between the resulting river flow impacts. An alternative is to examine basin sensitivity to changing climate, through the application of uniform changes in precipitation and temperature.

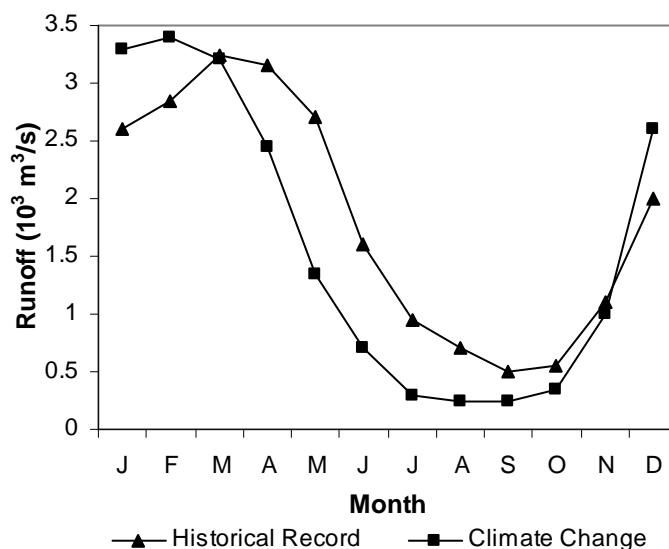


Figure 2. Hypothetical runoff patterns under current and potential climate change scenarios

A significant body of knowledge exists regarding the impact of climate change on river flows (e.g. Gleick, 1986; Arnell & Reynard, 1996). Many suggest significant sensitivity to climate change.

Reibsame et al. (1995) examined climate impacts on several major rivers. For the Zambezi, GCM scenarios suggested that mean annual runoff may decline by 17% or rise by 18%. The most severe change occurred with the Nile which under one scenario mean flows fell to less than a quarter of their historic level. Overall, Reibsame et al. (1995) note that river basin sensitivity increases with aridity, and this, to some degree, explains the severe fall in Nile flows.

Despite differences between the study techniques used and river basin characteristics, Arnell (1996) drew the following conclusions:

- 1 Runoff is relatively more sensitive to precipitation change than temperature change.
- 2 River basins tend to amplify changes in precipitation.

Whilst changes in annual runoff are a useful indicator, often the seasonal changes are more profound. For example, Mimikou et al. (1995) found that for the Mesohora basin in Greece a 20% fall in precipitation accompanied by a 4°C temperature increase resulted in a 35% reduction in annual runoff. However, the impact on summer flows was almost twice as large, with the fall in winter limited to 16%. This pattern is repeated in many other studies and is a result of changes in soil moisture content.

### 3.2 Hydroelectric Generation

Hydropower potential is defined by the river flow, and therefore changes in flow due to climate change will alter the energy potential. More importantly, as most hydropower schemes are designed for a particular river flow distribution, plant operation may become non-optimal under altered flow conditions.

The capability of a given hydro installation to generate electricity is limited by its storage and turbine capacities. These place limits on the amount of carry-over storage to allow generation during dry spells, and also the degree to which benefit can be derived from high flows.

A number of studies have examined the impact of climate change on hydropower production (those listed in Table 1 are a representative sample). Published results suggest that the climate sensitivity of energy production is related to the storage available: in general terms the greater the degree of storage the lower the sensitivity. Additionally, turbine capacity limits the ability of schemes to take advantage of higher flows.

Other than energy volumes, the impact on generation reliability has been examined in a number of studies (e.g. Mimikou & Baltas, 1997). Garr & Fitzharris (1994), among others, relate both hydropower

production and energy demand to climatic variables in their examination of how climate change will affect the ability of the electricity supply system to meet demand.

Table 1. Examples of potential changes in annual hydro generation resulting from changes in temperature and precipitation.

Region/River	Temperature	Precipitation	Production
Nile River*	+4.7°C	+22%	-21%
Indus River*	+4.7°C	+20%	+19%
Colorado River **	+2.0°C	-20%	-49%
New Zealand ***	+2.0°C	+10%	+12%

Notes: \* Reibsame et al. (1995), \*\* Nash & Gleick (1993), \*\*\* Garr & Fitzharris (1994).

### 3.3 Revenue and finance

Despite such studies, none published to date has quantified the potential impact on the perceived or actual financial performance of hydro stations.

Hydro is characterised by low operational costs but high capital costs. As a result, the debt repayment period for a hydro scheme is often significantly longer than for fossil-fuelled plant. Despite high fossil-fuel costs, hydro will often be at a disadvantage, and would not be favoured by short-term orientated investors. As with all generation methods, electricity sales revenue is the only way of servicing the capital debt. If reductions in runoff and output were to lead to reductions in revenue, this would adversely affect the return on investment and hence the perceived attractiveness of the plant. Therefore, there is a possibility that potential schemes would not be pursued.

If potential hydro schemes are abandoned or production from existing facilities is limited by runoff changes, then the likely alternative is that fossil-fuelled stations will have to be constructed to cover the deficit. Not only would this require additional capital to be used, but also would probably result in additional carbon emissions, thus exacerbating climate change (Whittington & Gundry, 1998).

Many large hydropower developments in less developed countries have been built with the intention of stimulating economic development. Often, these are internationally financed and repaid in hard currency. Reductions in revenue may make it difficult to repay the debt, severely stressing weak economies, while the shortfall in electricity availability will hamper Governments' development attempts (Whittington & Gundry, 1998).

The magnitude of capital investment required for hydropower installations, together with the increasing penetration of private capital in the industry makes it imperative that project analysis takes account of potential climatic effects.

To assess the threat that climate change poses to future hydropower investment, there is a requirement for a robust methodology. The diverse nature of hydropower installations and climatic conditions precludes any form of accurate regional or global analysis at this stage. Therefore, an analysis on a case by case basis is necessary.

To assess the impact on investment it is necessary to consider the problem from the standpoint of a potential investor. They will be primarily concerned with the impact on a range of investment indicators, and, as such, a methodology derived from traditional hydropower appraisal was devised.

The techniques of hydropower appraisal are long established. However, the continuing reliance on historic flows to indicate future flow conditions is not prudent given the prospect of climate change. Some recent project appraisals have attempted to deal with climate change by uniformly altering river flows. Unfortunately, this practice is inadequate as it fails to take into account the tendency of a river basin to amplify precipitation changes.

The complexity of the task necessitates a software tool, the basic specifications for which are introduced elsewhere (Harrison et al., 1998) and illustrated schematically in Figure 3. The use of a rainfall-runoff model removes the reliance on historic flows by providing a link between climatic variables and river flows. This enables the relationship between climate and financial performance to be examined effectively.

The rainfall-runoff model is calibrated using monthly historic river flow and climate data. Following this, suitable operational, financial and economic data enables simulations to be rapidly carried out.

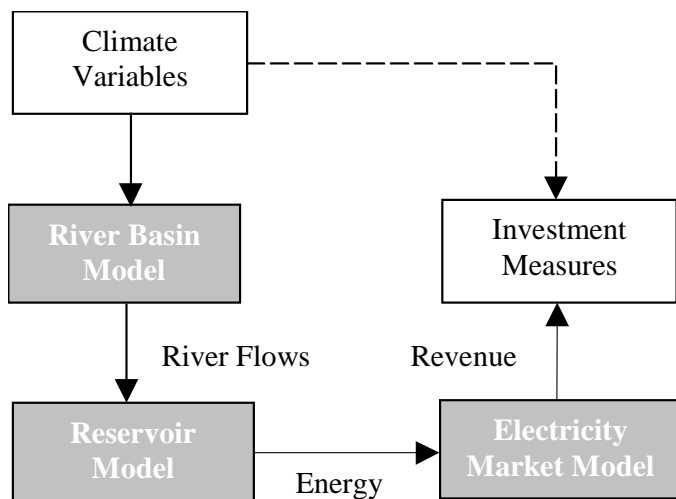


Figure 3. Software tool structure.

Software has been developed by the authors to meet the required specifications. The software was tested using an actual planned scheme: sample results are presented here. The chosen scheme has limited reservoir storage capacity and is intended to operate as a run-of-river plant. The river flow regime is highly seasonal and is not influenced by snowfall. Basic operational and financial information was extracted from a traditional feasibility study of the scheme. Simulations indicated that the software delivers production estimates and investment measures that are comparable with figures found in the feasibility study.

A sensitivity study was carried out, with the model driven by historic precipitation and temperature data uniformly changed to simulate climate change. Results suggest that runoff and energy production are both sensitive to rainfall change, and that runoff changes are significantly greater than the precipitation variation. Although storage is limited, production sensitivity is lower than runoff. Energy production is less sensitive to increases in flow as much of the excess flow is spilled.

The assumption of a single energy price means that the investment sensitivity follows a similar pattern to production. Figure 4 shows the response of internal rate of return (IRR) and discounted payback to rainfall variations. IRR is positively related to rainfall, whilst discounted payback period shows the opposite trend. The greater sensitivity to flow reductions can be seen.

Net present value is not shown in Figure 4 as the NPV variations significantly larger. The compounding effect of revenue changes over the project lifetime means that NPV ranges from -200% to 140%.

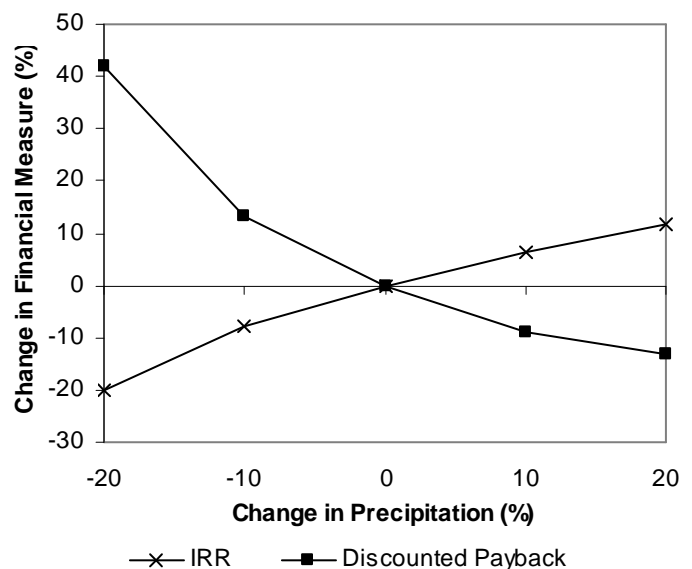


Figure 4. Sensitivity of financial appraisal measures to uniform changes in precipitation

Although these results are only preliminary, they indicate that the financial performance of the scheme is sensitive to rainfall changes. Furthermore, they imply that in regions that experience reduced rainfall, hydropower could become less competitive. As such, investment in hydropower projects will be less likely, and the ability to limit climate change will be reduced.

## 6 CONCLUSIONS

Climatic change is expected to result from the release of significant quantities of man-made emissions of greenhouse gases. One of the key methods of limiting the extent of change is through the use of renewable energy sources, including hydropower. Unfortunately, the reliance of hydropower on climatic conditions means that the changes predicted may affect it adversely. In particular, and given the increasing importance of private capital within the electricity industry, the financial performance of hydro schemes may be damaged. Subsequently, hydropower will be less competitive and alternative, presumably fossil-fuelled schemes will take precedence, reducing our ability to reduce greenhouse gas emissions.

A range of impacts on river flows and hydropower production have been identified, together with a consideration of the potential consequences of failing to take account of climate change when planning hydro schemes. A methodology and associated software tool have been briefly introduced which enable quantification of changes in investment performance as a result of changes in climate. Preliminary results of its use on a planned scheme are presented. The results indicate that investment measures show significant sensitivity to changes in rainfall. This implies that in regions that experience reductions in rainfall, hydropower will become less competitive. Therefore, investment in hydro projects is less likely to occur and our ability to control greenhouse emissions is lessened.

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